STUDIES ON THE SWELLING OF FOODS. II. ON THE DETERMINATION OF THE SWELLING VELOCITIES OF SEVERAL KINDS OF CEREALS

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ON THE DETERMINATION OF THE SWELLING VELOCITIES OF SEVERAL KINDS OF CEREALS

By

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The authors constructed an apparatus for determining the swelling velocities of different kinds of dried foodstuffs, and measured the swelling velocity of rice. The total volumes of those samples and water unexpectedly increased in the early stage. Those phenomena were reported in the first paper, and the subsequent results obtained from measuring several kinds of cereals other than rice will be reported in this paper.

Materials

The cereals the swelling velocities of which were measured are as follows:-

(a) Crushed sample of polished SASASIGURE.

The polished SASASIGURE which was measured in the previous experiment (1) was crushed and seived into 20-60 mesh's grains.

(b) Other cereals.

Polished barley	Humidity is	14.2	percent
Pressed barley	〃	12.4	〃
Foxtail millet, unpolished	〃	13.9	〃
Japanese barnyard millet, unpolished	〃	14.5	〃
Wheat, unpolished	〃	14.0	〃
Corn	〃	13.1	〃
Small red bean	〃	16.2	〃
Hemp-seed	〃	11.8	〃
Rape-seed	〃	10.9	〃

The humidities of these samples were determined by the method of drying in the atmosphare at 105°C.

Results

1. Polished and crushed SASASIGURE.

The decrease in the total volume of the crushed sample of polished SASASIGURE is shown in Tables 1 and 2 and Figs. 1 and 2.

Table 1. The decrease of the total volume of the polished and crushed SASASIGURE and water, *before* they were exhausted.

150 g of sample and 240 *ml* of water.

Time	Decrease of total volume	Time	Decrease of total volume
5.5 min	0.51 *ml*	2hr00min	0.06 *ml*
6	0.49		
7	0.47	3hr00min	0 00
8	0.43		
9	0.40	4hr00min	−0.05
10	0.37		
11	0.36	5hr00min	−0.08
12	0.35		
13	0.33	6hr00min	−0.09
14	0.33		
15	0.31	7hr00min	−0.10
20	0.28		
30	0.24	8hr00min	−0.14
40	0.21		
50	0.18	9hr00min	−0.16
1hr 00 min	0.16		

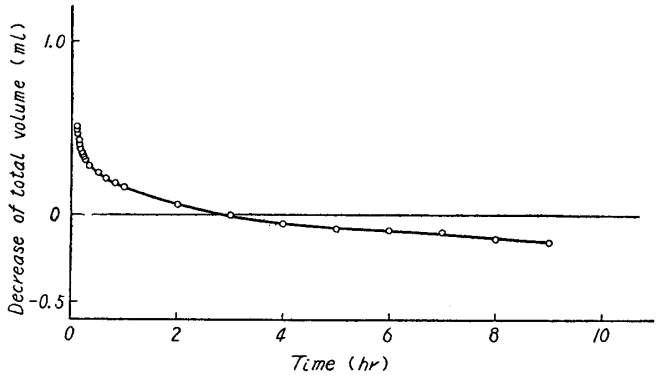

Fig. 1. The velocity curve of the decrease of total volume of the polished and crushed SASASIGURE and water, *before* they were exhausted.

The fluctuations shown in every measurements are normal and any abnormal phenomenon which was found in the case of polished SASASIGURE of the original grain is not shown in this case.

It is quite natural that the velocity of swelling is very quick in comparison with that shown in the measurement of the same kind in the original grain.

Table 2. The decrease of the total volume of the polished and crushed SASASIGURE and water, *after* they were exhausted.

150 g of sample and 240 *ml* of water.

Time	Decrease of total volume	Time	Decrease of total volume
2.5 min	0.56*ml*	30min	0.04*ml*
3	0.51		
3.5	0.47	1hr00min	0.02
4	0.41		
5	0.31	2hr00min	0.00
6	0.26		
7	0.23	3hr00min	0.00
8	0.21		
9	0.18	4hr00min	−0.02
10	0.16		
15	0.11	5hr00min	−0.02
20	0.08		

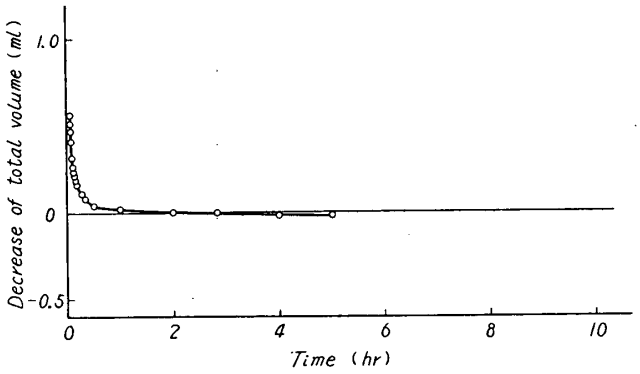

Fig. 2. The velocity curve of the decrease of total volume of the polished and crushed SASASIGURE and water, *after* they were exhausted.

2. Polished barley.

The total volume which was measured before the sample was exhausted decreased normally as shown in Table 3 and Fig. 3, and reached to equilibrium after about 6hr from the start of the swelling. But when measured after it was exhausted, the decrease of total volume continued longer than 6hr. When Fig. 4 is set against Fig. 3, however, it can be easily seen

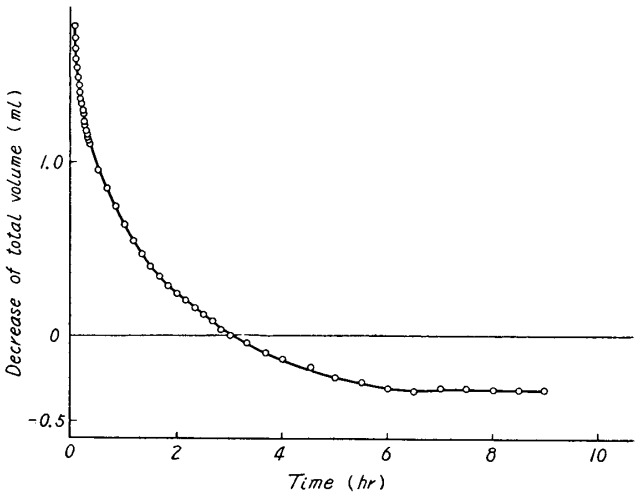

Fig. 3. The velocity curve of the decrease of total volume of the polished barley and water, *before* they were exhausted.

Table 3. The decrease of the total volume of the polished barley and water, *before* they were exhausted.
150 g of sample and 240 *ml* of water.

Time	Decrease of total volume	Time	Decrease of total volume
2.5 min	1.78*ml*	2hr00 min	0.24*ml*
3	1.71	10	0.20
4	1.65	20	0.16
5	1.59	30	0.12
6	1.54	40	0.08
7	1.48	50	0.03
8	1.44		
9	1.40	3hr00 min	0.00
10	1.36	20	−0.04
11	1.33	40	−0.10
12	1.30		
13	1.27	4hr00 min	−0.14
14	1.23	30	−0.19
15	1.21		
16	1.18	5hr00 min	−0.24
17	1.16	30	−0.27
18	1.14		
19	1.12	6hr00 min	−0.30
20	1.10	30	−0.33
30	0.95		
40	0.85	7hr00 min	−0.30
50	0.74	30	−0.31
1hr 00 min	0.64	8hr00 min	−0.31
10	0.54	30	−0.32
20	0.47		
30	0.40	9hr00 min	−0.32
40	0.34		
50	0.29		

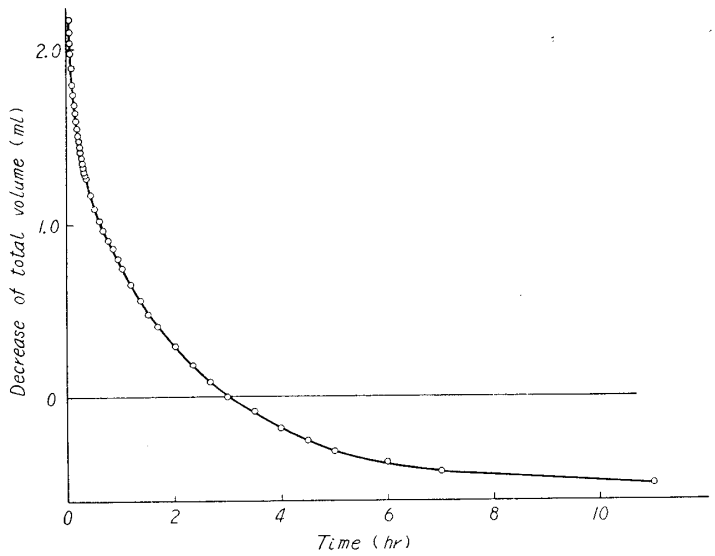

Fig. 4. The velocity curve of the decrease of total volume of the polished barley and water, *after* they were exhausted.

Table 4. The decrease of the total volume of the polished barley and water, *after* they were exhausted.
150g of sample and 240*ml* of water.

Time	Decrease of total volume	Time	Decrease of total volume
1.5 min	2.17*ml*	1hr00 min	0.75*ml*
2	2.10	10	0.65
2.5	2.04	20	0.56
3	1.98	30	0.48
4	1.90	40	0.41
5	1.80		
6	1.74	2hr00 min	0.30
7	1.68	20	0.19
8	1.64	40	0.09
9	1.59		
10	1.55	3hr00 min	0.00
11	1.51	30	−0.08
12	1.48		
13	1.44	4hr00 min	−0.18
14	1.41	30	−0.25
15	1.38		
16	1.35	5hr00 min	−0.31
17	1.33		
18	1.30	6hr00 min	−0.37
19	1.28		
20	1.26	7hr00 min	−0.43
25	1.17		
30	1.09	11hr	−0.50
35	1.02		
40	0.97	26hr	−0.70
45	0.91		
50	0.86		
55	0.80		

that the point of the velocity of the total volume decreases after the sample was exhausted is quicker than the other. The total volume decrease within 170 min's time, that is, from 10 min after the beginning of the measurement to 180 min shows more than 10 percent difference, being 1.55 *ml* when the sample was exhausted before the measurement, but becomes 1.36 *ml* when it was not exhausted.

3. Pressed barley.

It is very difficult to measure its swelling velocity of this sample before it was exhausted, because there is a large volume of air in its rough texture. The values which were measured after it was exhausted show a normal decrease of the total volume as shown in Table 5 and Fig. 5.

4. Foxtail millet.

This sample is not polished and covered with a hull and a seed coat, but its swelling velocity is fairly high. The velocity measured before the sample was exhausted is rather low in the early stage of swelling, but after it was exhausted it shows the standard type of the total volume decrease.

5. Japanese barnyard millet.

The graph of the total volume decrease of this sample shows a standard

Table 5. The decrease of the total volume of the pressed barley and water, *after* they were exhausted.
75g of sample and 240*ml* of water.

Time	Decrease of total volume	Time	Decrease of total volume
5 min	4.56*ml*	29 min	1.36*ml*
5.5	4.38	30	1.31
6	4.21	31	1.26
6.5	4.06	32	1.22
7	4.01	33	1.17
7.5	3.88	34	1.14
8	3.75	35	1.09
8.5	3.63	36	1.06
9	3.51	37	1.02
9.5	3.41	38	0.99
10	3.32	39	0.96
10.5	3.22	40	0.93
11	3.13	45	0.78
11.5	3.04	50	0.67
12	2.96	55	0.58
12.5	2.88		
13	2.80	1hr00 min	0.51
13.5	2.73	5	0.45
14	2.65	10	0.39
14.5	2.59	15	0.34
15	2.53	30	0.23
16	2.40	45	0.16
17	2.27		
18	2.18	2hr00 min	0.11
19	2.08		
20	1.99	3hr00 min	0.00
21	1.90		
22	1.82	4hr00 min	−0.04
23	1.72		
24	1.66	5hr00 min	−0.07
25	1.59		
26	1.53	6hr30 min	−0.13
27	1.48		
28	1.42	7hr30 min	−0.18

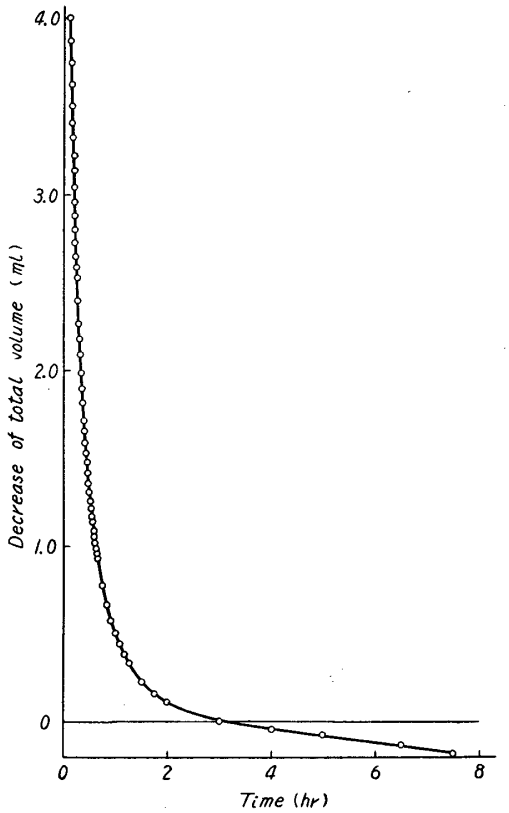

Fig. 5. The velocity curve of the decrease of total volume of the pressed barley and water, *after* they were exhausted.

Table 6. The increase and decrease of the total volume of the foxtail millet and water, *before* they were exhaused. 75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total valume
3min	0.94*ml*	3hr00 min	0.00*ml*
4	0.90	30	−0.17
5	0.88		
6	0.86	4hr00 min	−0.37
8	0.82	30	−0.61
10	0.81		
12	0.79	5hr00 min	−0.88
14	0.78	30	−1.14
16	0.77		
18	0.76	6hr00 min	−1.40
20	0.75	30	−1.61
30	0.70		
40	0.66	7hr00 min	−1.79
50	0.62	30	−1.91
1hr00 min	0.56	8hr00 min	−1.99
10	0.51	30	−2.04
20	0.47		
30	0.42	9hr00 min	−2.07
40	0.38	30	−2.08
50	0.33		
		10hr00min	−2.08
2hr00 min	0.29	30	−2.08
10	0.25		
20	0.21	11hr00 min	−2.03
30	0.16	30	−2.00
40	0.11		
50	0.05		(germinated)

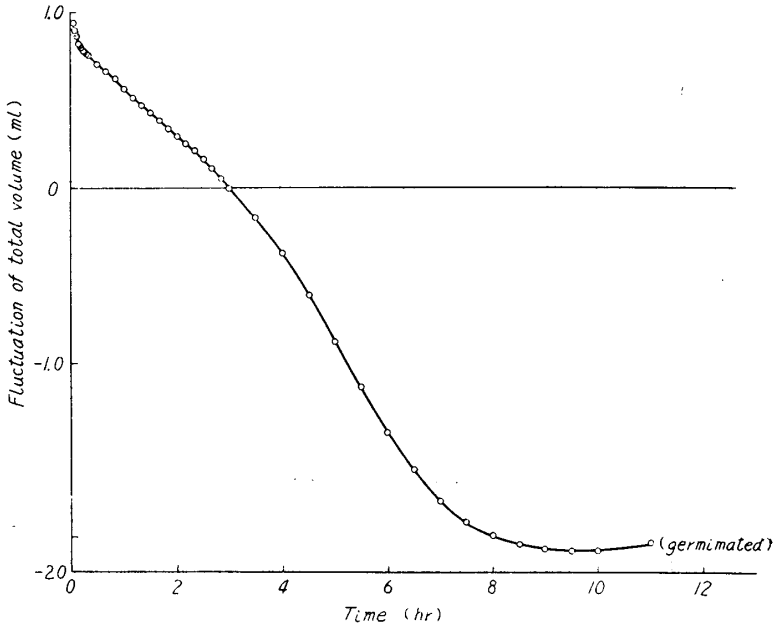

Fig. 6. The velocity curve of the fluctuation of total volume of the foxtail millet and water, *before* they were exhausted.

Table 7. The increase and decrease of the total volume of the foxtail millet and water, *after* they were exhausted.
75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
2min	2.54*ml*	4hr00min	−0.27*ml*
2.5	2.38	30	−0.36
3	2.24		
3.5	2.14	5hr00min	−0.42
4	2.06	30	−0.47
6	1.84		
8	1.64	6hr00min	−0.50
10	1.53	30	−0.53
12	1.46		
14	1.39	7hr00min	−0.55
16	1.33	30	−0.55
20	1.25		
30	1.10	8hr00min	−0.55
40	0.97	30	−0.54
50	0.87		
		9hr00min	−0.51
1hr00min	0.77	30	−0.49
10	0.69		
20	0.62	10hr00min	−0.46
30	0.55	30	−0.44
40	0.49		
50	0.42	11hr00min	−0.41
		30	−0.38
2hr00min	0.35		
20	0.23	12hr00min	−0.36
40	0.11	30	−0.33
			(germinated)
3hr00min	0.00		
30	−0.17		

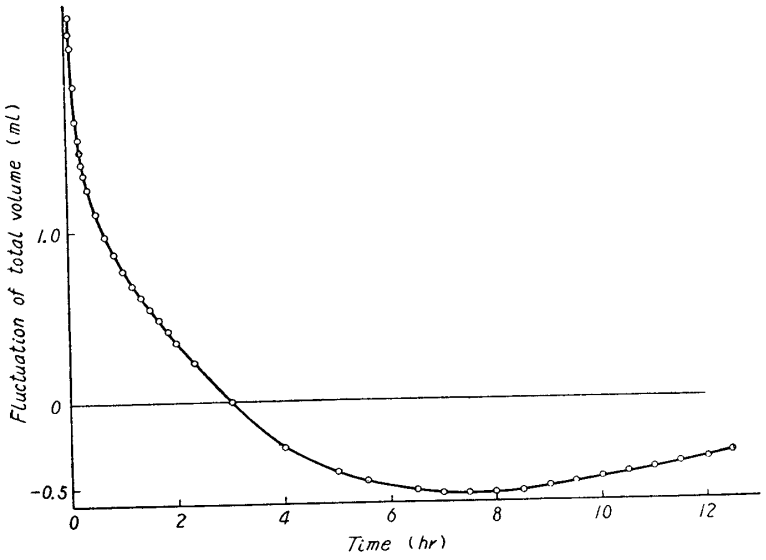

Fig. 7. The velocity curve of the fluctuation of total volume of the foxtail millet and water, *after* they were exhausted.

one. The total volume decrease measured before it was exhausted comes up to an equilibrium value, but on the other hand that which was exhausted swells fairly quick in the early stage, and 3hr later, the swelling nearly comes to a stop.

Table 8. The increase and decrease of the total volume of the Japanese barnyard millet and water, *before* they were exhausted.

75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
3min	5.04*ml*	2hr00min	1.42*ml*
4	4.98	5	1.26
5	4.95	10	1.10
6	4.92	15	0.95
7	4.90	20	0.80
8	4.87	25	0.66
9	4.85	30	0.53
10	4.83	35	0.42
12	4.77	40	0.31
14	4.73	45	0.22
16	4.68	50	0.14
18	4.64	55	0.07
20	4.59		
22	4.53	3hr00min	0.00
24	4.48	10	−0.11
26	4.43	20	−0.20
28	4.38	30	−0.27
30	4.32		
35	4.17	4hr00min	−0.47
40	4.02	30	−0.60
45	3.87		
50	3.71	5hr00min	−0.66
55	3.57	30	−0.70
1hr00min	3.41	6hr00min	−0.71
5	3.25		
10	3.09	7hr00min	−0.73
15	2.90		
20	2.75	8hr00min	−0.69
25	2.58		
30	2.41	9hr00min	−0.65
35	2.25		
40	2.08		
45	1.92		
50	1.75		
55	1.58		

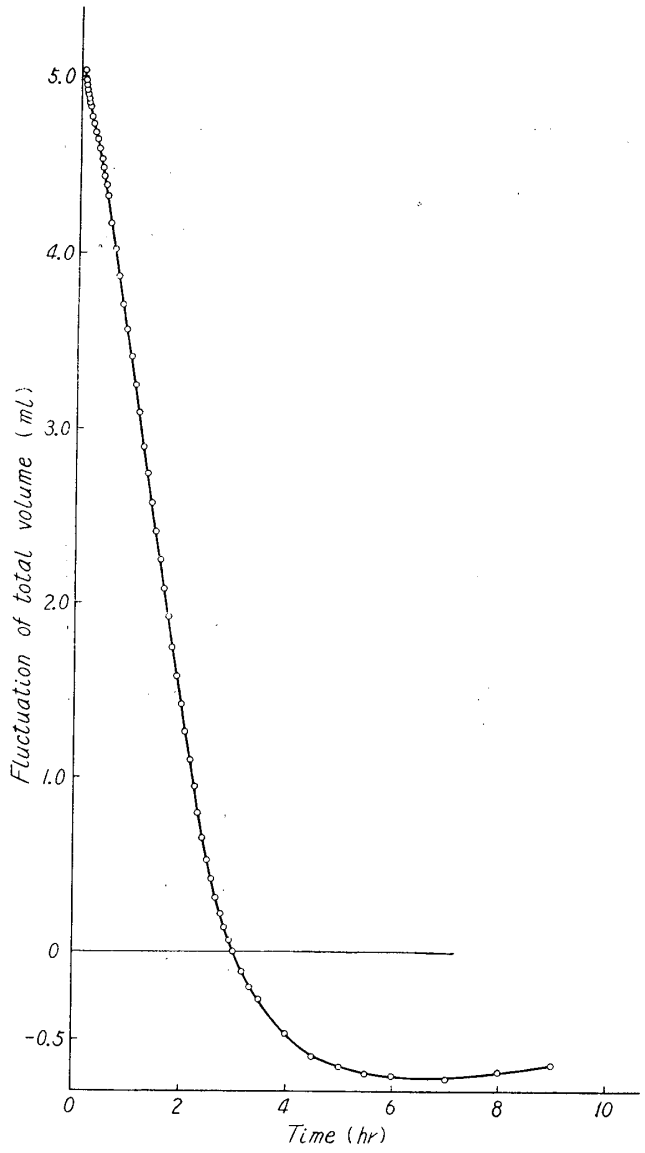

Fig. 8. The velocity curve of the fluctuation of total volume of the Japanese barnyard millet and water, *before* they were exhausted.

Table 9. The increase and decrease of the total volume of the Japanese barnyard millet and water, *after* they were exhausted.

75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
3min	3.21*ml*	1hr00min	0.63*ml*
3.5	2.97	10	0.51
4	2.79	20	0.42
4.5	2.64	30	0.34
5	2.52		
5.5	2.42	2hr00min	0.18
6	2.33	30	0.07
7	2.19		
8	2.07	3hr00min	0.00
9	1.97	30	−0.06
10	1.90		
12	1.78	4hr00min	−0.11
14	1.68	30	−0.15
16	1.59		
18	1.52	5hr00min	−0.19
20	1.45	30	−0.21
25	1.30		
30	1.18	6hr00min	−0.24
35	1.06	30	−0.27
40	0.95		
45	0.87	7hr00min	−0.29
50	0.78		
55	0.70	8hr00min	−0.31
		9hr00min	−0.32
		10hr00min	−0.31

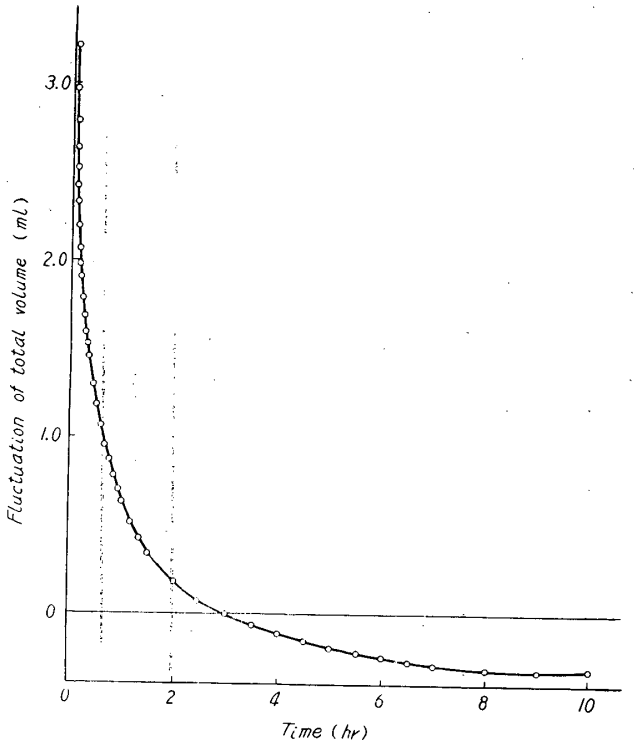

Fig. 9. The velocity curve of the fluctuation of total volume of the Japanese barnyard millet and water, *after* they were exhausted.

6. Wheat.

The total volume shows an appearance to have increased immediately after the water was pourd into the measuring vessel as is shown in Table 10 and Fig. 10, but when these values are carefully examined the conclusion seems to be that the total volume does not fluctuate in the early stage of the swelling.

Table 10. The increase and decrease of the total volume of the wheat and water, *before* they were exhausted.

75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
8min	0.90*ml*	2hr00min	0.29*ml*
10	0.91	20	0.17
12	0.92	40	0.07
14	0.92		
16	0.92	3hr00min	0.00
18	0.91	30	−0.07
20	0.91		
25	0.89	4hr00min	−0.12
30	0.88	30	−0.15
40	0.83		
50	0.78	5hr00min	−0.17
1hr00min	0.73	6hr00min	−0.18
20	0.59		
40	0.44	7hr00min	−0.18

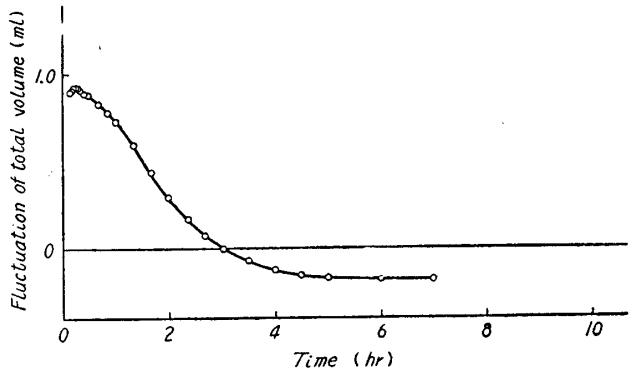

Fig. 10. The velocity curve of the fluctuation of total volume of the wheat and water, *before* they were exhausted.

7. Corn.

As for the values measured before the sample was exhausted, the fluctuation of the total volume is very indistinct two to three hour after the swelling started, and the values in their reappearance are inferior to those of other samples, for many air bubbles rose up from the sample.

When the values were measured after it was exhausted, the shape of the fluctuation curve fairly changed. For about 1hr at the first stage of swelling, the decrease of the total volume is normal, and after that the

Table 11. The increase and decrease of the total volume of the corn and water, *before* they were exhausted.

75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
5min	−0.09*ml*	8hr00min	−0.52*ml*
6	−0.08	30	−0.59
7	−0.07		
8	−0.06	9hr00min	−0.64
9	−0.05	30	−0.70
10	−0.05		
20	−0.02	10hr00min	−0.76
1hr00min	−0.02	11hr00min	−0.87
30	0.02		
		12hr00min	−0.97
2hr00min	0.03		
30	0.00	13hr00min	−1.07
3hr00min	0.00	14hr00min	−0.13
30	−0.02		
		15hr00min	−1.19
4hr00min	−0.04		
30	−0.07	16hr00min	−1.23
5hr00min	−0.11	17hr00min	−1.26
30	−0.16		
		18hr00min	−1.27
6hr00min	−0.23		
30	−0.31	19hr00min	−1.31
7hr00min	−0.38	20hr00min	−1.32
30	−0.45		

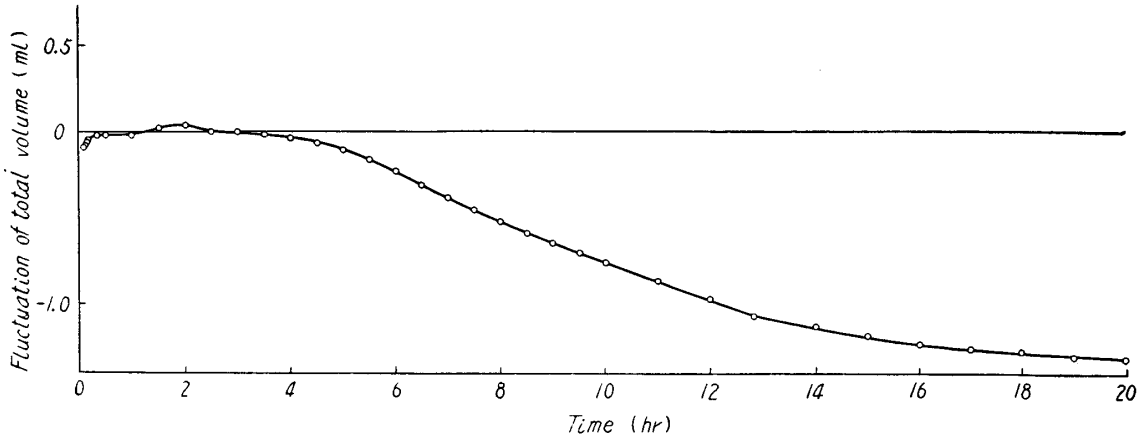

Fig. 11. The velocity curve of the fluctuation of total volume of the corn and water, *before* they were exhausted.

Table 12. The increase and decrease of the total volume of the corn and water, *after* they were exhausted.

75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
2min	1.24*ml*	9hr00min	−0.58*ml*
3	1.14	30	−0.64
4	1.06	10hr00min	−0.69
5	1.02	11hr00min	−0.80
6	0.97	12hr00min	−0.90
7	0.92	13hr00min	−1.00
8	0.89	14hr00min	−1.09
9	0.86	15hr00min	−1.17
10	0.83	16hr00min	−1.25
15	0.72	17hr00min	−1.32
20	0.63	18hr00min	−1.40
25	0.55	19hr00min	−1.46
30	0.47	20hr00min	−1.52
35	0.42	21hr00min	−1.57
40	0.36	22hr00min	−1.63
45	0.32	23hr00min	−1.67
50	0.27	24hr00min	−1.71
55	0.24	25hr00min	−1.75
1hr00min	0.21	26hr00min	−1.78
30	0.09	27hr00min	−1.81
2hr00min	0.05	28hr00min	−1.84
30	0.02	29hr00min	−1.87
3hr00min	0.00		
30	−0.02		
4hr00min	−0.05		
30	−0.10		
5hr00min	−0.14		
30	−0.19		
6hr00min	−0.24		
30	−0.30		
7hr00min	−0.35		
30	−0.41		
8hr00min	−0.47		
30	−0.52		

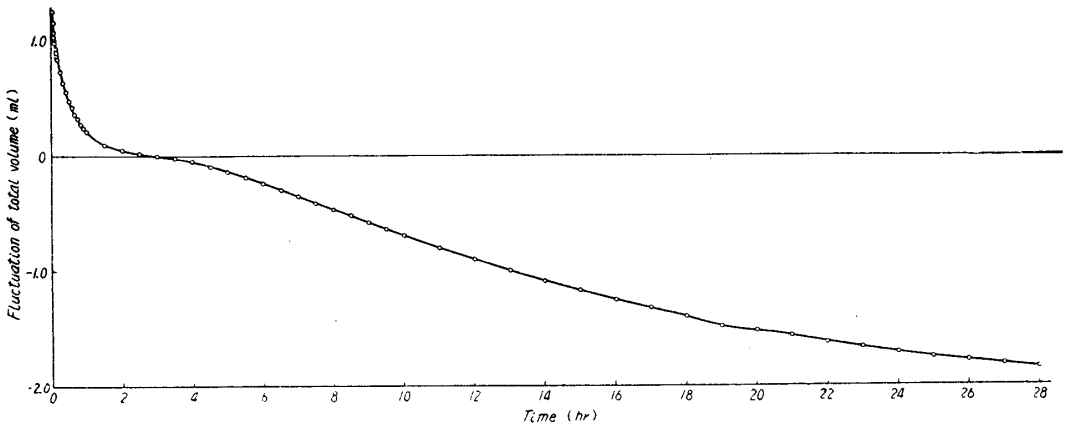

Fig. 12. The velocity curve of the fluctuation of total volume of the corn and water, *after* they were exhausted.

decrease nearly stopped, and then at 5hr from the beginning, the decrease is resumed.

8. Small red bean.

When the measurement-taking was carried on before it was exhausted, the work was completely interrupted and the values did not reappear, because many air bubbles rose up into the measuring tube from the sample. So, these values could not be averaged as shown in Table 13 and Fig. 13. Even when

Table 13. The increase and decrease of the total volume of the small red beans and water, *before* they were exhausted. 75g of sample and 290*ml* of water.

Time	Fluctuation of total volume		
	1st experiment	2nd experiment	3rd experiment
30min	0.31*ml*	0.00*ml*	0.11*ml*
1hr00min	0.04	0.04	0.10
30	0.06	0.04	0.08
2hr00min	0.05	0.04	0.07
30	0.03	0 03	0.02
3hr00min	0.00	0.00	0.00
30	−0.03	−0.04	0.00
4hr00min	−0.07	−0.02	0.00
30	−0.12	−0.02	−0.04
5hr00min	−0.17		
30	−0.23	−0.06	
6hr00min	−0.31	−0.08	
30	−0.38	−0.10	
7hr00min	−0.46	−0.11	
30	−0.51	−0.12	
8hr00min	−0.55	−0.12	
30	−0.59	−0.14	
9hr00min	−0.62	−0.18	
30	−0.69	−0.21	
10hr00min	−0.73	−0.24	
30	−0.78		
11hr00min	−0.84	−0.27	
30	−0.88	−0.34	
12hr30min	−0.95	−0.37	
13hr30min		−0.40	
14hr00min	−0.97	−0.40	
15hr00min	−0.96		
16hr00min	−0.93		
17hr00min	−0.90		
18hr00min	−0.88		
19hr00min	−0.84		
20hr00min	−0.80		
21hr00min	−0.73		
22hr00min	−1.82		
22hr00min	−0.61		
30	−0.54		

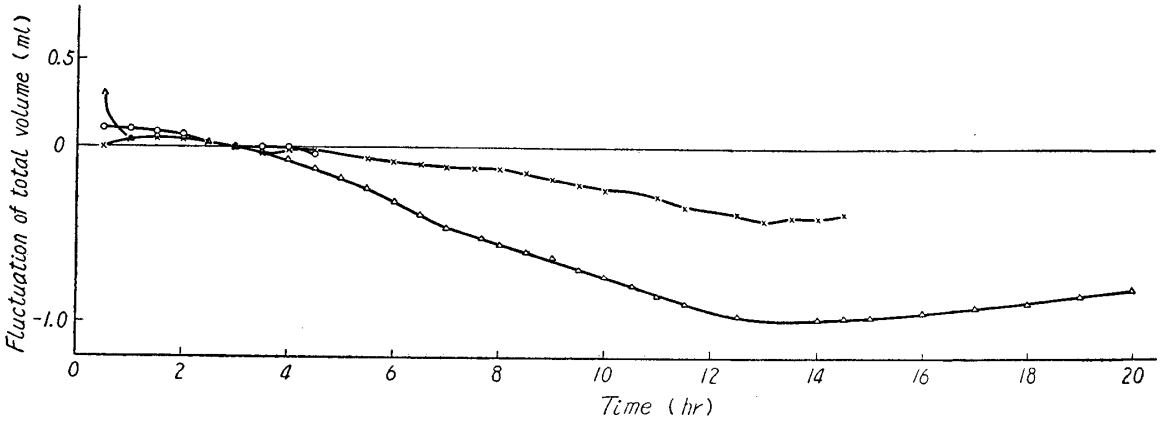

Fig. 13. The velocity curve of the fluctuation of total volume of the small red beans and water, *before* they were exhausted.

it was exhausted, the swelling seemed scarcely to take place for two to three hour after water was poured into it.

Table 14. The increase and decrease of the total volume of the small red beans and water, *after* they were exhausted.

75g of sample and 290*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
10min	0.20*ml*	11hr00min	−1.07*ml*
15	0.18	30	−1.13
20	0.15		
25	0.14	12hr00min	−1.19
30	0.12	30	−1.24
40	0.11		
		13hr00min	−1.31
1hr00min	0.09	30	−1.35
30	0.07		
		14hr00min	−1.40
3hr00min	0.00		
		15hr00min	−1.44
4hr00min	−0.09		
		16hr00min	−1.53
5hr00min	−0.19		
		17hr00min	−1.58
6hr00min	−0.30		
		18hr00min	−1.63
7hr00min	−0.45		
		19hr00min	−1.68
8hr00min	−0.63		
		20hr00min	−1.74
9hr00min	−0.78		
30	−0.88	21hr00min	−1.80
10hr00min	−0.96	22hr00min	−1.82
30	−1.01		

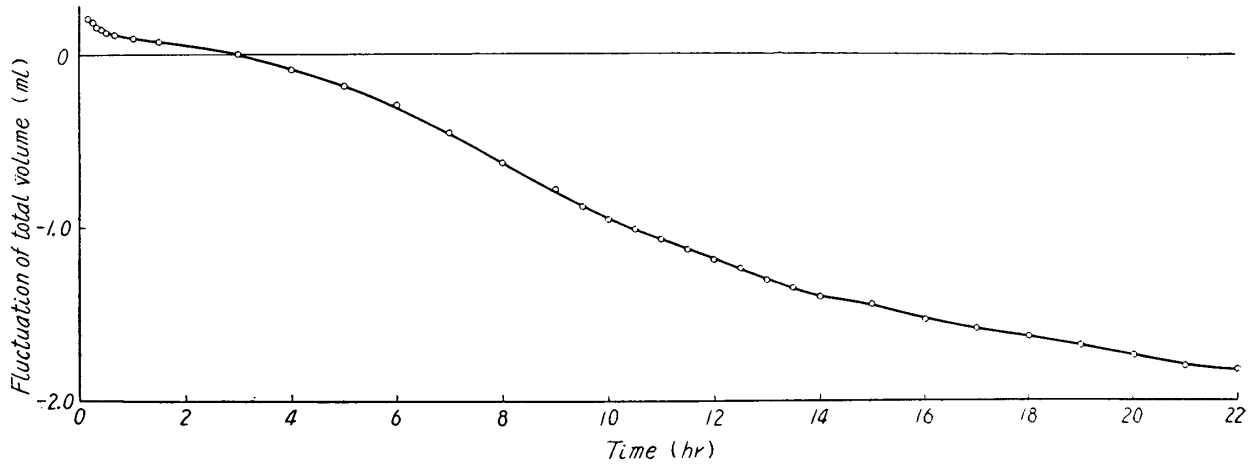

Fig. 14. The velocity curve of the fluctuation of total volume of the small red beans and water, *after* they were exausted.

9. Hemp-seed.

Both samples which were exhausted before the measurement and those not exhausted show the normal types of the total volume decreasing.

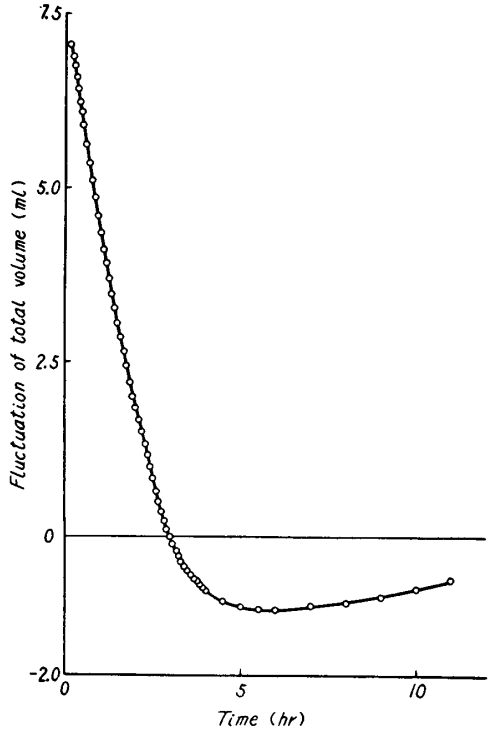

Fig. 15. The velocity curve of the fluctuation of total volume of the hemp-seed and water, *before* they were exhausted.

Table 15. The increase and decrease of the total volume of the hemp-seed and water, *before* they were exhausted.
75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
8min	7.06*ml*	2hr00min	1.84*ml*
9	7.02	5	1.67
10	6.98	10	1.50
11	6.94	15	1.33
12	6.89	20	1.17
13	6.84	25	1.00
14	6.79	30	0.83
15	6.73	35	0.65
16	6.68	40	0.51
17	6.63	45	0.36
18	6.57	50	0.23
19	6.51	55	0.11
20	6.45		
21	6.40	3hr00min	0.00
22	6.34	5	−0.10
23	6.29	10	−0 20
24	6.23	15	−0.28
25	6.18	20	−0.37
26	6.12	25	−0.44
27	6.07	30	−0.50
28	6.01	35	−0.56
29	5.95	40	−0.61
30	5.89	45	−0.66
35	5.62	50	−0.70
40	5.36	55	−0.74
45	5.09		
50	4.85	4hr00min	−0.78
55	4.60	30	−0 93
1hr00min	4.36	5hr00min	−1.02
5	4.11	30	−1.05
10	3.92		
15	3.69	6hr00min	−1.05
20	3.48		
25	3.27	7hr00min	−1.01
30	3.06		
35	2.85	8hr00min	−0.96
40	2.64		
45	2.44	9hr00min	−0.87
50	2.22		
55	2.03	10hr00min	−0.75
		11hr00min	−0.60

10. Rape-seed.

The phenomenon which seems to be analogonus to the total volume increase appears clearly in the cases of both samples—one exhausted and the other not exhausted. And then, a special shape which has some valley appears on the curve.

Table 16. The increase and decrease of the total volume of the hemp-seed and water, *after* they were exhausted.
75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
3min	10.65*ml*	1hr10min	5.18*ml*	5hr00min	−3.71*ml*
5	10.40	12	5.07	10	−3.97
6	10.28	14	4.96	20	−4.24
7	10.16	16	4.84	30	−4.49
8	10.04	18	4.73	40	−4.73
9	9.86	20	4.62	50	−4.97
10	9.80	22	4.51		
11	9.69	24	4.40	6hr00min	−5.20
12	9.57	26	4.30	10	−5.41
13	9.46	28	4.19	20	−5.63
14	9.36	30	4.07	30	−5.84
15	9.26	32	3.96	40	−6.04
16	9.16	34	3.86	50	−6.25
17	9.07	36	3.76		
18	8.97	38	3.65	7hr00min	−6.45
19	8.87	40	3.54	10	−6.63
20	8 77	42	3.44	20	−6.83
21	8.67	44	3.34	30	−7.01
22	8.58	46	3.24	40	−7.19
23	8.49	48	3.12	50	−7.37
24	8.40	50	3.04		
25	8.31	52	2.94	8hr00min	−7.55
26	8.21	54	2.84	10	−7.72
27	8.14	56	2.74	20	−7.88
28	8.06	58	2.65	30	−8.03
29	7.97			40	−8.18
30	7.89	2hr00min	2.56	50	−8.33
32	7.73	10	2.10		
34	7.58	20	1.64	9hr00min	−8.47
36	7.43	30	1.20	10	−8.61
38	7.28	40	0.79	20	−8.74
40	7.13	50	0.38	30	−8.87
42	6.99				
44	6.85	3hr00min	0.00	10hr00min	−9.23
46	6.70	10	−0.36	30	−9.59
48	6.57	20	−0.72		
50	6.43	30	−1.06	11hr00min	−9.98
52	6.30	40	−1.39		
54	6.16	50	−1.76	12hr00min	−10.29
56	6.04				
58	6.91	4hr00min	−2.05	13hr00min	−10.64
		10	−2.36		
1hr00min	5.79	20	−2.63	14hr00min	−10.71
2	5.66	30	−2.90		
4	5.54	40	−3.16	15hr00min	−10.85
6	5.41	50	−3.44		
8	5.28			16hr00min	−10.77
				17hr00min	−10.68

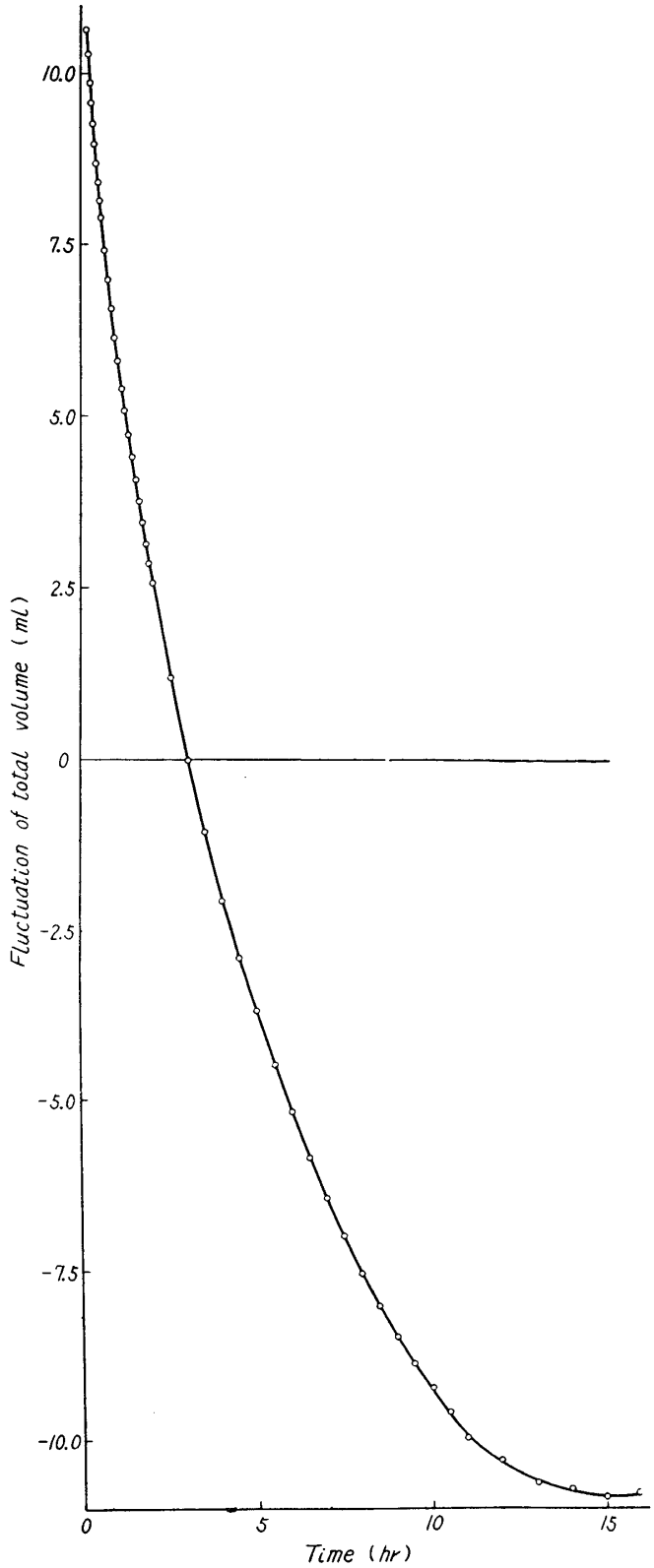

Fig. 16. The velocity curve of the fluctuation of total volume of the hemp-seed and water, *after* they were exhausted.

Table 17. The increase and decrease of the total volume of the rape-seed and water, *before* they were exhausted.
75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume
5min	2.86*ml*	1hr20min	0.19*ml*
6	2.92	30	−0.08
7	2.96	40	−0.25
8	2.98	50	−0.33
9	2.99		
10	2.99	2hr00min	−0.35
12	2.97	30	−0.21
14	2.94		
16	2.89	3hr00min	0.00
18	2.83	30	0.17
20	2.75		
22	2.68	4hr00min	0.24
24	2.60	30	0.25
26	2.51		
28	2.42	5hr00min	0.23
30	2.33	30	0.20
35	2.09		
40	1.85	6hr00min	0.17
45	1.63	30	0.17
50	1.38		
55	1.17	7hr00min	0.19
		30	0.22
1hr00min	0.94		
5	0.75	8hr00min	0.27
10	0.54		
15	0.37	9hr00min	0.41

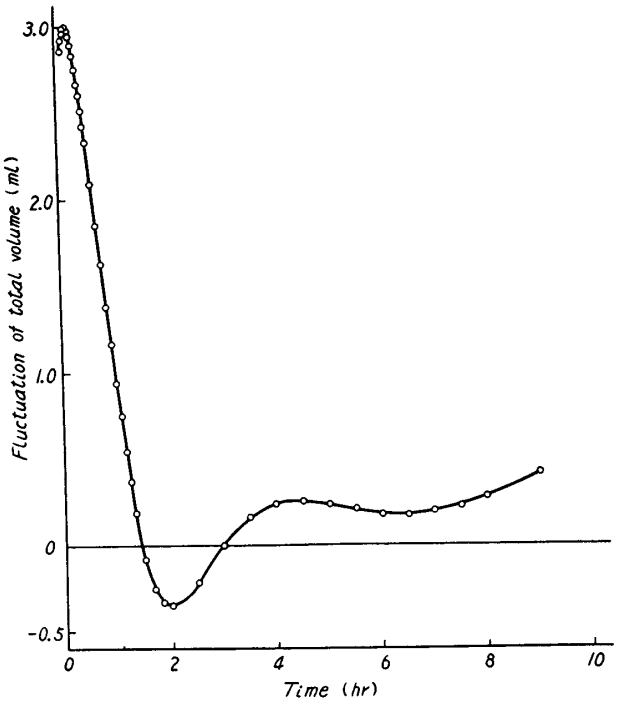

Fig. 17. The velocity curve of the fluctuation of total volume of the rape-seed and water, *before* they were exhausted.

Table 18. The increase and decrease of the total volume of the rape-seed and water, *after* they were exhausted.

75g of sample and 240*ml* of water.

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
2min	3.78*ml*	44	2.52*ml*	3hr00min	0.00*ml*
3	4.02	46	2.40	30	0.05
4	4.14	48	2.29		
5	4.21	50	2.18	4hr00min	0.07
6	4.26	52	2.08	30	0.02
7	4.28	54	1.97		
8	4.29	56	1.86	5hr00min	−0.07
9	4.29	58	1.77	30	−0.19
10	4.27				
12	4.23	1hr00min	1.66	6hr00min	−0.30
14	4.17	5	1.42	30	−0.41
16	4.09	10	1.21		
18	4.00	15	1.01	7hr00min	−0.49
20	3.90	20	0.83	30	−0.56
22	3.79	25	0 68		
24	3.69	30	0.54	8hr00min	−0.61
26	3.57	35	0.44	30	−0.64
28	3.46	40	0.35		
30	3.33	45	0.27	9hr00min	−0.67
32	3.21	50	0.20	30	−0.69
34	3.10	55	0.15		
36	2.98			10hr00min	−0.68
38	2.87	2hr00min	0.11	30	−0.66
40	2.75	30	−0.01		
42	2.64			11hr00min	−0.63

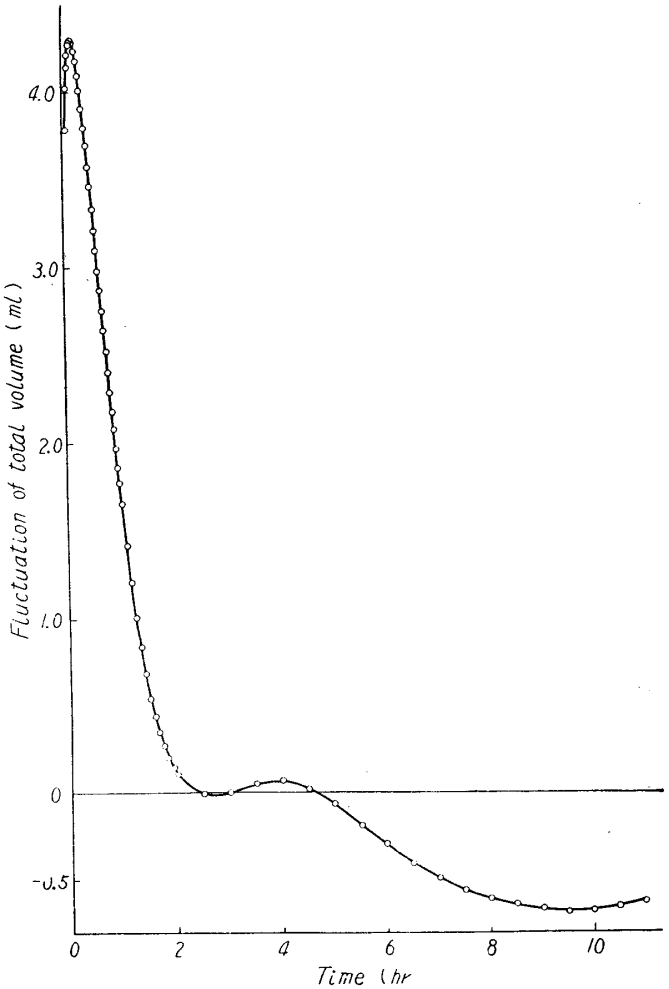

Fig. 18. The velocity curve of the fluctuation of total volume of the rape-seed and water, *after* they were exhausted.

Discussion

1. The effect of the exhaust to the velocity of swelling.

It is a well known fact that to make the substance swell, the air which is held on the surface and/or in the inner parts of that substance will interfere with its contact with water, and the velocity of the swelling will be quite delayed when water is added to the untreated substances. Those phenomena are also typically observed in the values of the swelling velocities by the authors' measurements.

In the measurements of the authors, they are not continued until the decreases of the total volumes reached to some equilibrium, but from these values, the aforesaid facts can be estimated when the decreases of total volumes extend below 0.05 *ml* per 1hr for 100 g of those samples (Table 19).

Table 19. The times when the decreases of total volume extend below 0.05 *ml*/1hr/100 g of sample.

Sample	Before the sample was exhausted	After the sample was exhausted
Polished non-glutinous rice	2hr	2hr
Polished glutinous rice	4hr	3hr
Polished SASASIGURE	3hr	6hr
Unpolished MIYAKOGANEMOTI	8hr	9hr30min
Polished and crushed SASASIGURE	2hr	1hr
Polished barley	5hr	7hr
Pressed barley	—	4hr
Foxtail millet	9hr	6hr30min
Japanese barnyard millet	6hr	7hr
Wheat	5hr	—
Corn	16hr	25hr
Small red bean	—	21hr
Hemp-seed	5hr	15hr
Rape-seed	4hr	9hr

This table shows some measurements of those which were exhausted shortened to one-third the time needed for establishing the equilibrium of

swelling to the other samples which were measured before they were exhausted.

In some cases where unpolished rice, corn and hemp-seed etc. are used, the velocities measured after they were exhausted are slower than the others, but even in those cases, if the values are examined in detail it is clear that these velocities become extremely slow at the middle of the swelling when the measurements were taken before the samples were exhausted, and the swelling seemed nearly to stop. But in reality, extremely a long time will be needded for the swelling to reach the equilibrium. Therefore, if those apparent equilibrium are taken for the real equilibrium, that substance which is thought to have swelled completely, is left in reality very defective in its swelling. This fact is very important in the practical food manufacturing. When dehydrated foods absorb water and swell, if the water goes into only the surface or only into their large crevices, the hydration will be imperfect; water must completely impregnate into the very microscopic spaces of the inner most. So it is very effective to exhaust foodstuffs of their air before they are brought into contact with water.

2. On the abnormality of the fluctuation of the total volume.

As the authors reported in the last paper, the abnormal phenomena were shown on the fluctuation of the total volume of rice and water, but when the same sample was crushed into coarse particles, this phenomena disappeared as shown in Tables 1 and 2 and Figs. 1 and 2.

In these measurement, we may well wonder whether the total volume is decreasing before the time when the measurement is started, because it is started in two to five minuts after the water is poured on to the sample, and the total volume increase has come to an end in this initial hour. But, as inferences are drawn from every result of the measurements of many samples and the shapes of the fluctuation curves of the total volumes it is certain on the whole that the total volume decrease is normal in this case. Thus it may safely be said that these abnormal phenomena takes place when rice in the form of "a grain of rice" begin to swell; and when it is crushed into small particles, this abnormality disappears, and so this phenomena may have same connection with the histological structure of the rice grain. But it is necessary to determine the behaviors of the products made of crushed rice in the shape of grains or other various forms.

Of the several kinds of cereals of the present measurements, such abnormal phenomena of the swelling as shown in the cases of rice are as follows;

Polished barley	Normal.
Pressed barley	Normal when measured after it was exhausted only.

Foxtail millet	When it is measured before it was exhausted, the values are disposed to become abnormal, but when exhausted, the values are normal.
Japanese barnyard millet	The same as the above.
Wheat	The values are disposed to become abnormal despite it is exhausted.
Corn	The same as the cases of foxtail millet and Japanese barnyard millet.
Small red bean	Abnormal.
Hemp-seed	Normal.
Rape-seed	Very abnormal.

In these various cases, "abnormal phenomena" of foxtail millet and Japanese barnyard millet are shown on the curves of the total volume decrease. The curve must be smooth from the beginning of the swelling but in these cases it is strained at the midway as is shown in Fig. 19 by the solid line. Such phenomena are shown in the case of the unpolished SASASIGURE which is measured after the sample was exhausted, but it is doubtful whether the phenomena in the case of foxtail millet and Japanese barnyard millet are the same as the total volume increase which is generally shown in the case of rice. As in these cases, both samples of foxtail millet and Japanese barnyard millet are unpolished, and so the interference must have occurred due to air which may be held in the interstice between their seed cases and their seed coats (the parts which put together shall be called "skin" hereafter) and their albumens.

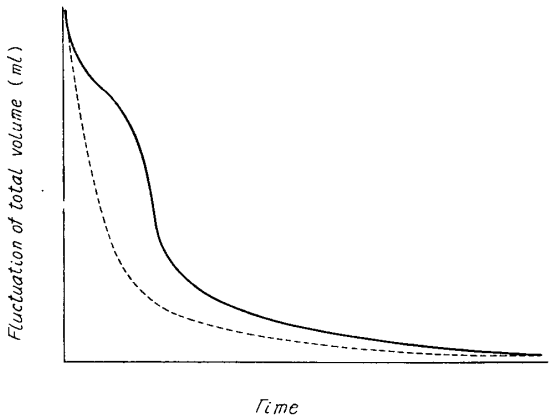

Fig. 19.

It is their skin which first comes into contact with water when water is poured in, and then in the first place the total volume will normally decrease by the swelling of their skin. But soon after this swelling will come to an end, and water will penetrate into the inner parts. When the sample comes into contact with water before being exhausted, the layer of air which is held in the interstice between the skin and the albumen must be displaced with water so that water which has passed through their skin may come into contact with the albumen. Then the supply of water from the skin to the albumen will delayed, which, in turn, delay the swelling of the albumen

for its swelling velocity is controled by the velocity of the water supply, and it was at this time that the slope of the curve will be strained.

On the contrary, when the sample which was exhausted before water is poured into those measuring vessels, water can be immediately absorbed into the albumen passing through the skin for the want of the layer of air between the skin and the albumen, and so the values which are measured show about normal shape.

The phenomena which are shown in the cases of corn and red bean may be the same. As the seed case and the seed coat of corn are thick and tough, and much air is kept closely among them, it is not easy that the air is replaced by water, and a long time will be required. These are reasoned from that so many air bubbles rise up when water is poured in, to make these measurement almost impossible, and the values thus gained are widely distributed. But, with the samples which are exhausted of air before measurements are taken, comparatively normal velocity curves are shown since these obstructions are removed. Nevertheless, the curves are fairly strained two to five hour after the beginning of the swelling. This straining in the case of the unpolished SASASIGURE, may be due, the authors presumed, to that the increase of the total volume and its decrease take place at the same time. But, in the case of corn, further studies must decide whether simultaneous occurrence of the increase and the decrease of the total volume, or some other simple reason, for instance, the structure of corn may cause the delay of the velocity of swelling. This should be studied in the future with both crushed and others.

In the case of small red bean, as it was polished by one of the authors (2), its seed case is of such a substance as to not permit water to defuse, and water must be absorbed only through the hilum, and air must also escape only through the hilum. And so, the velocity of water in absorption and the escaping air interfere with each other. Owing to these causes, the values which are measured before the sample was exhausted are very slow in their velocities. But, when the sample was exhausted, the air which is held in the inner part of the albumen is taken off, and so water which difused into the seed case is absorbed normally, and normal values are measured. Nevertheless, the pathway for water in the seed case is limited to its hilum, which makes the quantity of the supplying water insufficient, which makes, in turn, the velocity of swelling low even at the beginning of the swelling when the velocity must be high.

Then, when the time is longer than 10hr, the seed case is locally thinned or cracked because of the expansion of the seed case due to swelling of the albumen and to strong osmotic pressure on it. And then, the water can be supplied directly without passing through the hilum, and the swelling velocity become fairly quick (cf. Fig. 13, the curve at the time of 8-12hr).

The cause of the strain of the swelling velocity curve must be the above mentioned one, and it is better to consider this case to be different from the abnormal phenomena of the rice.

In the case of wheat, the fluctuation of the total volume at the beginning of swelling is better to be taken not for increase but for no change. In this case, the abnormality will be caused by the effects of the seed coat or the seed case, since the sample is unpolished, and its fluctuation of the total volume will show a normal decrease. Similarly, in the case of barley of the polished and of the pressed one, very typical fluctuations are shown. It is very interesting that the polished barley, the wheat and the rice are of a sort in their shape of grain, but the polished barley and wheat differ from rice in their swelling properties.

Therefore, it can be concluded that so far as the measurements up to this time are concerned, the total volume increase which is measured in the case of rice is fairly rare one among various cereals, and it is the phenomenon which rice shows when it is in the shape of a grain as it is.

In addition to the measurements with several kinds of cereals, the swelling of rape-seed was measured for comparison, and its fluctuation is so complicated that such phenomena is never witnessed among any kinds of cereals. It will be ruled out from this discussion since it is yet to be found in the future.

3. On the empilical formura of the swelling velocity.

As reported in the previous paper, when the sample swells normally, the velocity can be expressed with some empirical formula. The empirical formula was calculated in the case of the polished barley which shows the most normal fluctuation.

From the beginning of the swelling till 40 min:-

$$V=2.21-0.85\log t$$

V is the increase and the decrease of the total volume of the sample and water which is expressed for that value at the time of 3hr from the beginning.
t is the time from the beginning of the swelling.

And after 50 min:-

$$V=2.92-1.29\log t$$

The values which are calculated from these formulas agree well with the observed values as shown in Table 20.

Table 20. The comparison of the calculated total volume decrease with the obserbed one.

Time	Obserbed value	Calculated value	Time	Obserbed value	Calculated value
2.5min	1.78*ml*	1.87*ml*	50min	0.74*ml*	0.73*ml*
3	1.71	1.80	60	0.64	0.63
4	1.65	1.70	70	0.54	0.54
5	1.59	1.62	80	0.47	0.47
6	1.54	1.55	90	0.40	0.40
7	1.48	1.49	100	0.34	0.34
8	1.44	1.44	110	0.29	0.29
9	1.40	1.40	120	0.24	0.24
10	1.36	1.36	130	0.20	0.19
11	1.33	1.33	140	0.16	0.15
12	1.30	1.29	150	0.12	0.11
13	1.27	1.26	160	0.08	0.08
14	1.23	1.24	170	0.03	0.04
15	1.21	1.21	180	0.00	0.00
16	1.18	1.19	200	−0.04	−0.05
17	1.16	1.16	220	−0.10	−0.10
18	1.14	1.14	240	−0.14	−0.15
19	1.12	1.12			
20	1.10	1.10	420	−0.30	−0.46
30	0.95	0.95			
40	0.85	0.85			

Summary

In succession to the previous paper, the swelling velocities were measured with several kinds of cereals, and the following results were found.

1) In the case of every sample, the velocities are fairly accelerated by means of exhaust before they come into contact with water, and in the case of the same sample, about a third of the time required to reach the equilibrium is reduced.

2) About the abnormal phenomena of the total volume fluctuation, no samples show such typical and severe abnormality as is shown by rice. No remarkable abnormality is shown even in the cases of barley and Japanese barnyard millet which rather resemble rice, and even when they show some abnormal phenomena, those phenomena disappear when the air is exhausted.

3) The fluctuation of the total volume is not abnormal when the rice are crushed into small grains.

4) The empirical formulas of the swelling velocity in the case of barley were caluculated, and the results are quite agreeable with the observed values.

References

1) Sato, K., S. Nagasawa (1960). Tohoku J. Agr. Res., **11**, 307.
2) Nagasawa, S. (1955). Nosan Kako Gijutsu Kenkyukai Shi, **2**, 211. (in Japanese)